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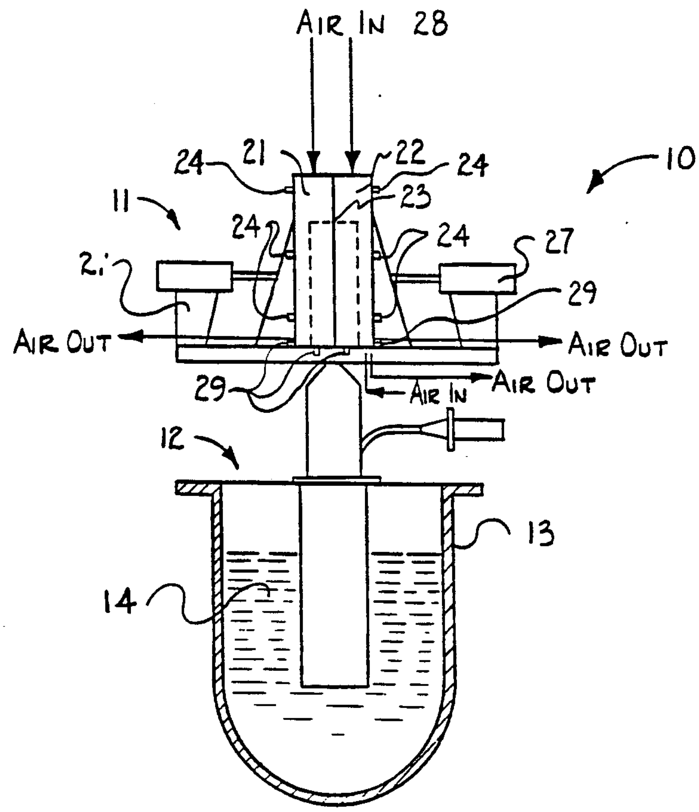
(57) Abstract

An electromagnetic pump for use in low pressure permanent mold (LPPM) (11) casting of molten metals (14) such as magnesium, magnesium alloys and magnesium composites which provides separate control of idle setting and mold filling, including a 12-coil electromagnetic pump (12) attached to a 6-coil pump in the same housing, wherein the 12-coil operates from its own power supply and associated controls for mold filling and the 6-coil pump operated from a separate power supply and associated controls for keeping the molten metal heated and in an idle position below the point of mold injection. The pump requires no auxiliary cooling and can be used with a wide variety of casting machines and mold configurations.



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ELECTROMAGNETIC PUMP

This invention relates to an electromagnetic pump and more particularly to an electromagnetic pump useful in low pressure permanent mold casting of molten metals. The electromagnetic pump is advantageously used for casting molten metals such as magnesium, magnesium alloys, and magnesium composites.

Electromagnetic (EM) pumps are known to be used, for example, in aluminum and magnesium processes and in the pumping of reactor coolants in the nuclear industries. None of the EM pumps of the prior art have been successfully used in a low pressure permanent mold (LPPM) process. The electromagnetic pumps of the prior art also have the disadvantage of requiring external cooling.

An EM pump is described in U.S. Patent No. 4,828,459, entitled "Annular Linear Induction Pump With An Externally Supported Duct", filed by H.C. Behrens, December 16, 1987. The electromagnetic pump of the present invention is an improved pump over the pump described in the U.S. Patent No. 4,828,459.

It is desired to provide an electromagnetic pump which (1) has the ability to operate at molten magnesium temperatures without auxiliary cooling; (2) has the ability to feed low pressure permanent mold die casting machines; (3) offers flexibility in design size for a wide range of casting machines; (4) provides a wide control range for maximum versatility in utilizing different mold configurations; and (5) incorporates into the pump an electrically heated stand-pipe which will keep the metal heated in the idle position just below the point of introduction into a mold.

The present invention is directed at an electromagnetic pump comprising a housing containing a first set of coils for mold filling and a second set of coils for mold filling, each of said first and second set of coils being separately and independently connected to a power supply and a control system, said second set of coils being adapted for holding molten metal at a predetermined level.

Figure 1 is a schematic view showing one embodiment of an apparatus of the present invention for casting billets or ingots.

Figure 2 is a front view of a billet apparatus of the present invention for use in the process of the present invention.

Figure 3 shows a partial cross-sectional view of the billet apparatus of Figure 2.

Figure 4 is a top view of the billet apparatus of Figure 2.

Figure 5 is a side view showing one embodiment of an electromagnetic pump for use in the process of the present invention.

Figure 6 is a partial front view of the electromagnetic pump of Figure 5.

Figure 7 is a partial cross-sectional view of the electromagnetic pump of Figure 5.

Figure 8 is a top view of Figure 5.

Figure 9 is a cross-sectional view taken along line 10-10 of Figure 5.

Figure 10 is a cross-sectional view taken along line 10-10 of Figure 5.

The present invention resides in an apparatus and process for producing LPPM castings from molten materials including molten metal, alloys and/or composites. An "LPPM casting" herein means low pressure permanent mold casting. The pressures used in the present invention are from 2 to 30 (13.8 to 207 kPa).

A single stage machine, i.e. a machine which is capable of producing one piece or part at one time, is used to produce a finished cast part. A finished cast product, for example a billet, produced by the process and apparatus of the present invention can be shipped "as-is" when it is removed from the machine. The product is useful, for example, in a remelt or extrusion process. The process and apparatus of the present invention provides, for example, a sound, clean billet with fine equiaxed grains.

As an illustration of the billets produced by the present invention, billets greater than 95 percent dense have been produced. Billets having a porosity of less than 4 percent are preferred. The billets should contain a minimum, if any, amount of large nonmetallic inclusions (NMI). Billets containing zero NMI per square inch (6.45 cm^2) of a size of greater than 0.020 inches (0.51 mm) in diameter have been produced. The NMI count in a billet is measured by standard methods such as optical microscopy of fractured surfaces. It is preferable that the billet contain fine (about 0.10 inches in diameter or less) equiaxed grains throughout the structure of the billet. The above billets are characterized as being good quality billets.

A variety of well known mold shapes can be used in the present invention such as billets, wheels, ingots, T-bars and the like. Sand molds may also be used in the present invention.

The yield of the operation herein depends on the size of the casting desired. Clearly, it is desired to produce a casting as efficiently and quickly as possible. Generally, castings may be produced at a rate of from 1 per minute to 1 per 20 minutes and preferably at least one casting per 10 minutes.

An advantage of the process and apparatus of the present invention is that it provides a means for casting molten metals such as magnesium, magnesium alloys, and magnesium composites.

Any magnesium or magnesium base alloy may be used in the present invention. For example, those containing various amounts of Al, Zn, Mn, rare earth metals, Zr, Ag, Y, Th, and the like, can be used. Alloys of magnesium such as AZ91, AZ31, EZ33, ZK60, AM 60 and other alloys listed in American Society for Testing and Materials (ASTM) B80-1987, page 34 are useful for processing in accordance with the present invention. All commercial and experimental alloys are useful in the present invention. Some examples of magnesium composites include AZ91 reinforced with 20 volume percent 600 grit SiC particulate; a magnesium-6 wt percent zinc alloy reinforced with 20 volume percent 1000 grit SiC particulate and all commercial and experimental magnesium alloys reinforced with 1 to 30 volume percent SiC, Al_2O_3 or B_4C of 1 to 50 microns in particle size.

Cooling means used in the present invention include any means which will provide "directional solidification" such as air, H_2O, glycol and the like. The molten material is cooled down to a temperature substantially below the molten material's solidification temperature before removing the product from the machine. Of course the solidification temperature and the cooling temperature used depends on the molten material used. The solidfication temperature of magnesium is 650°C. For example, when casting a magnesium part, the casting part is cooled to a temperature of from 200° to 400°C to remove the part from the mold.

The solidification time in the present invention is substantially influenced by part size, mold design and type of metal used in casting. Generally, the time of solidification of a cast part is from 2 to 4 minutes.

The materials of construction of the apparatus of the present invention are those used for machines such as mild steel, cast steel, stainless steel, or a high carbon steel such as C4140. Generally, materials should not be reactive to the molten material and stable at process conditions. For example, the mold parts should be made of hard steel because the parts may be subject to thermal shock.

"Sprue" means the entry part to the mold cavity. In low pressure permanent mold casting, metal may freeze within the sprue that feeds the mold. To minimize freezing in the sprue, the sprue may be heated by any conventional means such as by electrical heating. Eliminating freezing within the sprue aids in increasing the production of billets. For example, once freezing within the sprue is eliminated, billets may be produced at a rate of about one billet every 3 to 10 minutes.

With particular reference to Figure 1, there is shown a casting apparatus, generally indicated by reference numeral 10, for producing billets and/or ingots from molten metal. The casting apparatus 10 includes a billet mold machine, generally indicated by reference numeral 11, an electromagnetic pump, generally indicated by reference numeral 12 and a crucible 13 with molten material 14 therein.

The billet mold machine 11, more clearly shown in Figures 2-4, comprises two mold halves 21 and 22 diametrically opposed for forming a mold cavity 23 when the halves are contacting each other in mirror-like fashion. Thermocouples 24 are placed in the top, middle and bottom of each of the halves to monitor the temperature in the mold halves. The top thermocouple is preferably positioned so that it extends through the mold half 22 to be in direct contact with the molten metal to indicate whether the mold is full with molten metal. The molds are slidably mounted on slide members. The slide members are, in turn, mounted on a support base plate 25 for slidably moving the halves to enable one to open or close the mold halves and position the halves on plate 25. The molds are connected by support structure 26 to an actuating means 27 such as hydraulic jacks for opening or closing the mold halves.

Cooling medium ports 28 in the top of mold are used to introduce a cooling medium through conduits 28b into the top of mold and cooling medium ports 29 in the bottom of the mold are used to exit the cooling medium such as air from the molds. The cooling medium circulates through the inside of the mold halves 21 and 22 through cooling medium channels 28a.

The cooling medium for cooling the molten metal in cavity 23 from top to the bottom may include, for example, air, a cooling liquid such as glycol, and the like. Sprue 30 may also contain cooling medium inlets (not shown) for introducing a cooling medium such as air to the sprue to cool the metal at the inlet 33 at the bottom of the billet machine.

The electromagnetic (EM) pump 12, is more clearly shown in Figures 5-10, and comprises an encased, insulated and heated pipe which will deliver and hold molten metal. The pump is used for feeding molten metal to the mold 11 and for maintaining the mold filled with molten metal during the casting operation.

More specifically, the electromagnetic pump 12 comprises an electrical box 40 with phased plug receptical. Electrical conduits 41 and 42 connect the electric box 40 to pump windings. A housing 43 contains a 12 coil 240 VAC core assembly, indicated generally as section A of the pump 12, and a 6 coil 110 VAC assembly, indicated generally as section B of the pump 12, and a heated stand pipe 44 for holding molten metal just below a point of mold entry. Lifting ear lugs 45 are used to lift and position the pump on a support platform to be held by flange 46. Hanger brackets 47 can also be used to support the pump 12 in position above a crucible 13. A conduit inlet 48 is used for connecting to a heater element 49 for heating the stand pipe 44 as shown in Figures 7 and 9. An insulation layer 50 of any conventional insulating material is placed around the pipe 44. An inert gas padding may be introduced through inlet 51 in box 40 for protecting the electrical and core systems of the pump from oxidation and/or deterioration at elevated operating temperatures.

In Figure 10, there is shown the housing 43 enclosing coils 52 and cores 53 around tube 55. A core rod 55 is centered in tube 54 to form an annulus 56 for pumping molten material therethrough to stand pipe 44.

In carrying out one embodiment of the present process, a low pressure casting of a round billet (cylindrically shaped body) is carried out using a single mold billet machine substantially shown in Figure 1 as follows:

The mold and all tools are preheated before use to above about 100°C. A melt furnace pot is used and can be protected by a flux suitable for use with molten magnesium or SF_6 gas.

A 12 coil EM pump as substantially shown in Figures 5-10, operating off 240v power supply is preferably used for feeding molten magnesium into the mold. The EM pump is attached to the bottom of the billet machine by a hanger assembly which allows the molten metal to fill the mold. A pan with a hole in the center is placed on the pump. The pump is turned on and a visual inspection of the metal flow and volume is noted for the filling speed and complete mold fill. All working parts are cycled to insure correct response.

The pot is set at a temperature of about 690°C. A pan test is run to make sure all electrical components are working as needed. The billet mold is preheated and can be purged with a gas such as SF_6, argon, CO_2 and the like prior to placement on pump. The mold is coated with any compatible mold coating such as a spinel for isolating the mold walls from the molten metal and for preventing the molten metal from wetting the mold walls. A mold release coating such as graphite spray is also preferably applied to the mold walls at about 400°C.

When the pump and the mold are ready for operation a pumping rate, predetermined from the pan test, will be applied to the mold. If a thermocouple in the top of the mold does not read a full mold then more power will be applied to the EM pump until a reading shows that the mold is full.

For the first few mold fills, only enough pressure will be applied to fill the mold. After looking at the finished billet a decision may be made to apply additional pressure.

When it has been determined that a full mold exists or that only a certain amount of metal can be introduced into the mold, the pump remains energized for a predetermined amount of time, for example, for about three minutes. The pump is then deenergized and the mold is left to cool for a period which will be determined at that time for example from previously prepared temperature charts.

The air flow rates and/or water flow rates for cooling the molten metal used in the present invention should be sufficient to provide the necessary cooling of the cast part. The rates are measured and can be controlled at a desired range depending on cooling rate desired. Generally, for example, the water flow rates range from 0.5 to 3 gal/min (1.89 to 11.4 lit/min) to provide the necessary cooling.

Care must be given when opening the mold to make sure no molten metal still exists in the mold. The billet is inspected for quality. The next injection will contain the previous billets data for run parameters.

The machine as substantially shown in Figure 1 is a single mold billet machine and is very similar to a low pressure die casting machine in that molten metal fills the mold through a fill hole located in the bottom center of the vertical mold. Magnesium metal fills the mold at about 700°C and is cooled, for example, using air injected through cooling ports in the top of the mold and through the cooling area at the introduction point of the mold.

Example 1

An apparatus substantially as shown in Figure 1 was used to prepare billets of a magnesium composite alloy AZ31B.

Ingots of AZ31B were melted in a 1500 pound (675 kg) steel crucible. A steel billet mold substantially as shown in Figures 2-4, with a mold cavity measuring 7.25 in (18.4 cm) in diameter by 25 in (63.5 cm) long, was placed directly over the crucible. Next, molten composite was pumped into the steel billet mold with an electromagnetic pump. Six billets weighing 70 pounds (31.5 kg) each, were produced at a rated of about one every nine minutes.

Billets of high quality were produced, i.e., the billets had reduced levels of oxide inclusions and voids and a smooth surface finish. Billets were made to a set shape and size without the necessary of risers.

The six low pressure permanent mold cast composite billets were x-rayed and the results showed that the billets had a minimal amount of internal porosity. Some of the billets were extruded into a 2-1/4 inch (57 mm) round rod with excellent surface quality, no porosity and very fine (i.e., 8-10 microns) grain size.

1. An electromagnetic pump comprising a housing containing a first set of coils for mold filling and a second set of coils for mold filling, each of said first and second set of coils being separately and independently connected to a power supply and a control system, said second set of coils being adapted for holding molten metal at a predetermined level.

2. The pump of Claim 1, including an electrically heated stand pipe for holding metal at a predetermined level just below a point of mold injection.

3. The pump of Claim 1 or 2, wherein the molten metal is selected from magnesium, an alloy of magnesium or a composite of magnesium.

4. The pump of Claim 1, 2 or 3, adapted for use in the low pressure permanent mold (LPPM) casting of molten metals which provides separate control of idle setting and mold filling, wherein said first set of coils is a 12-coil electromagnetic pump and said second set of coils is a 6-coil pump adjacent thereto such that the 12-coil pump operates from its own power supply and

control system for mold filling and the 6-coil pump operates from a separate power supply and control system for keeping the molten metal heated in the idle position in the electrically heated stand pipe at a level below the point of mold injection.

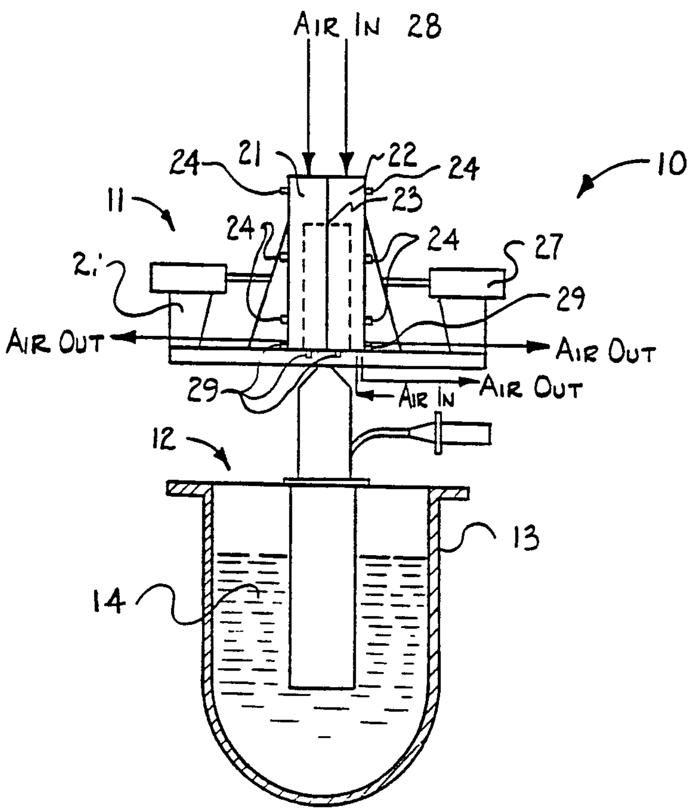

FIGURE 1V

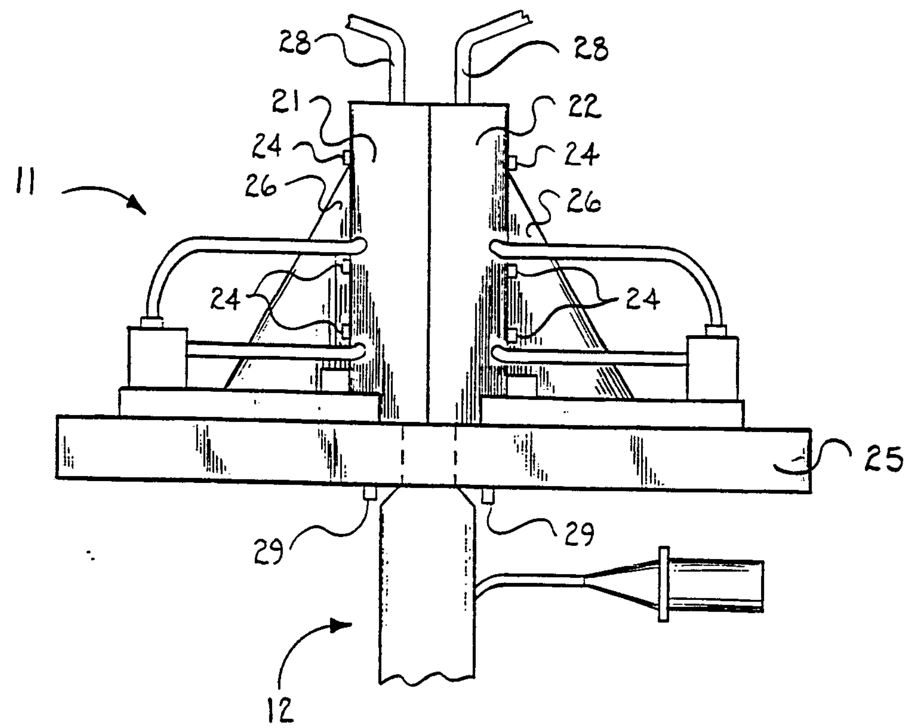

FIGURE 2

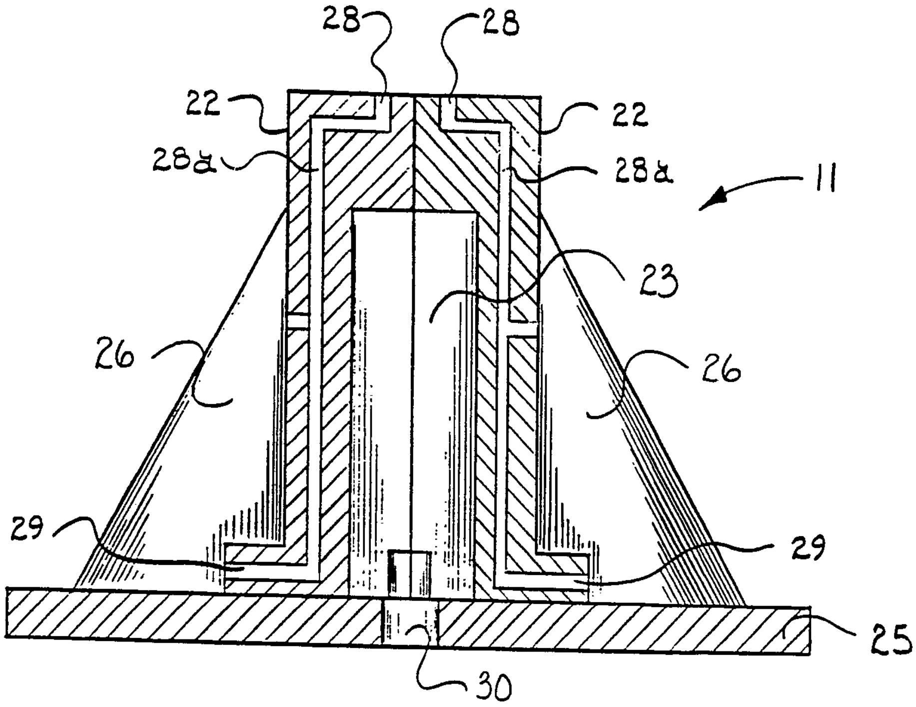

FIGURE 3

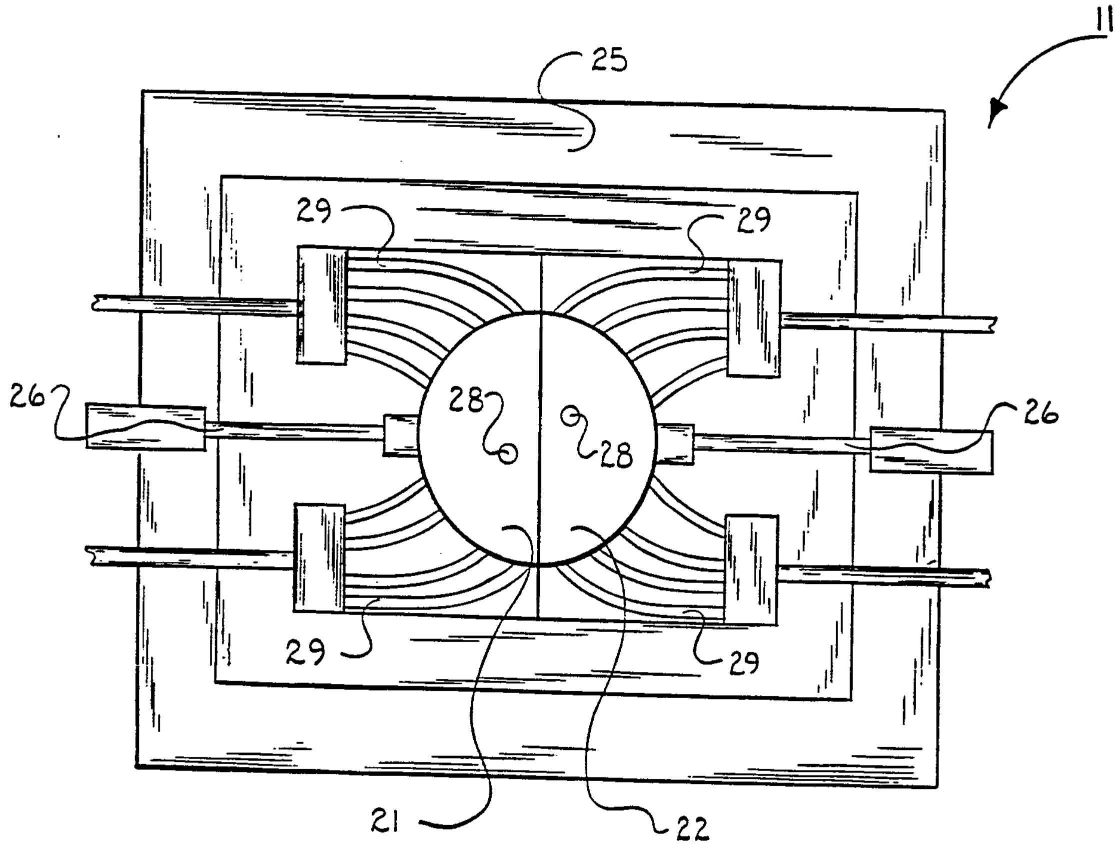

FIGURE 4

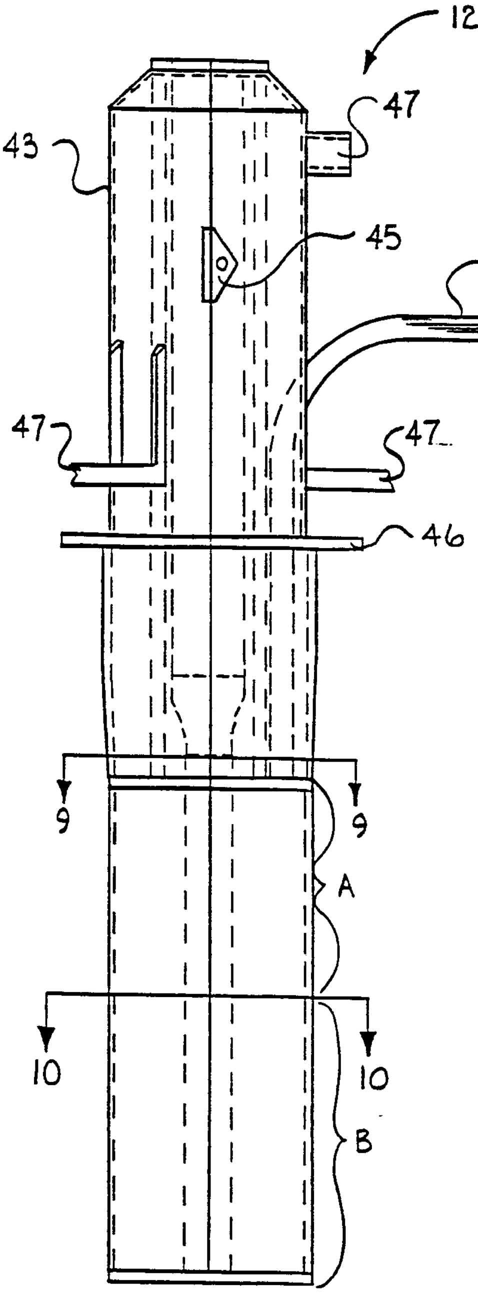

Figure 5

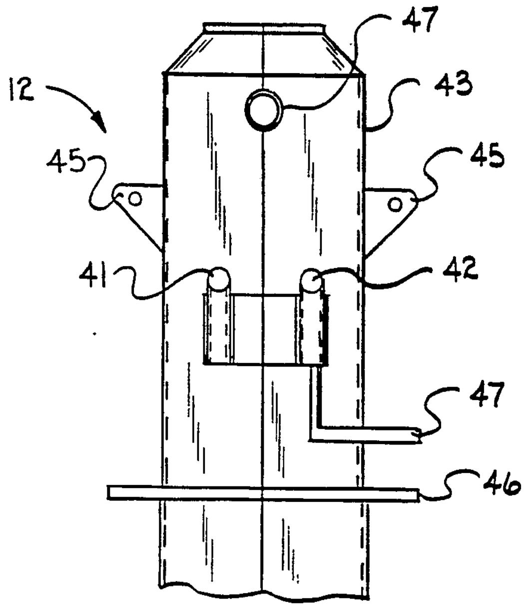

Figure 6

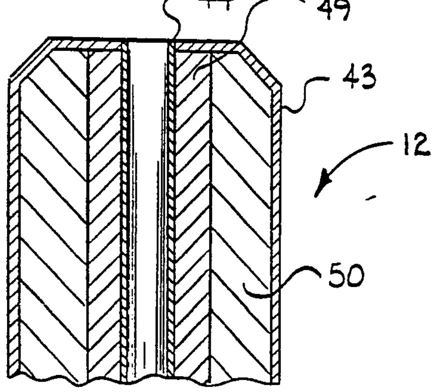

Figure 7

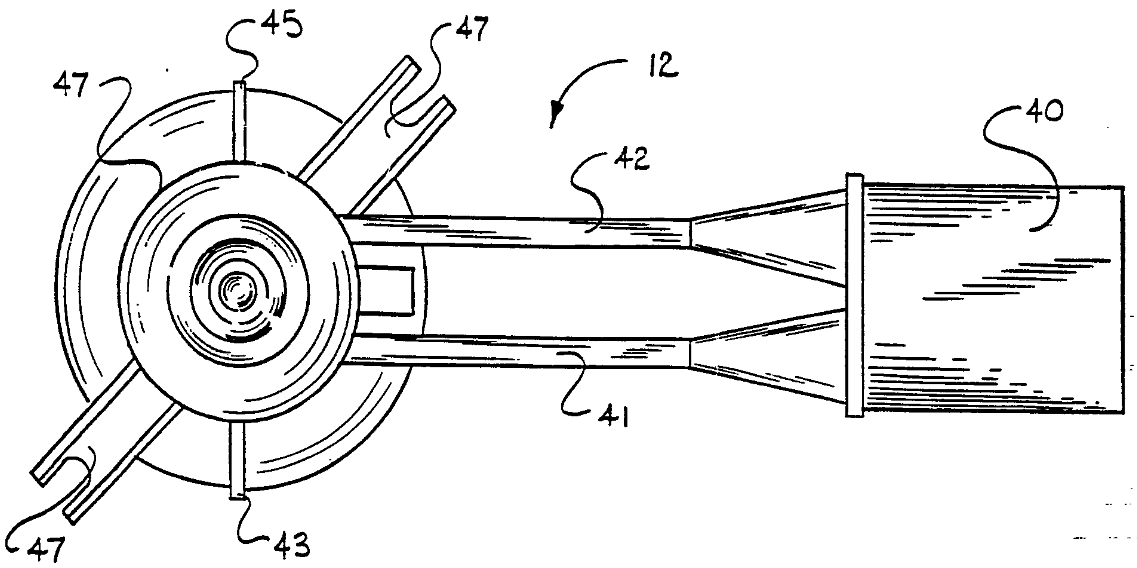

FIGURE 8

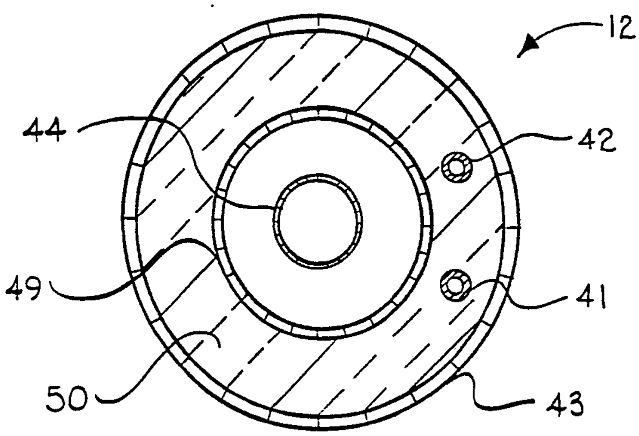

FIGURE 9

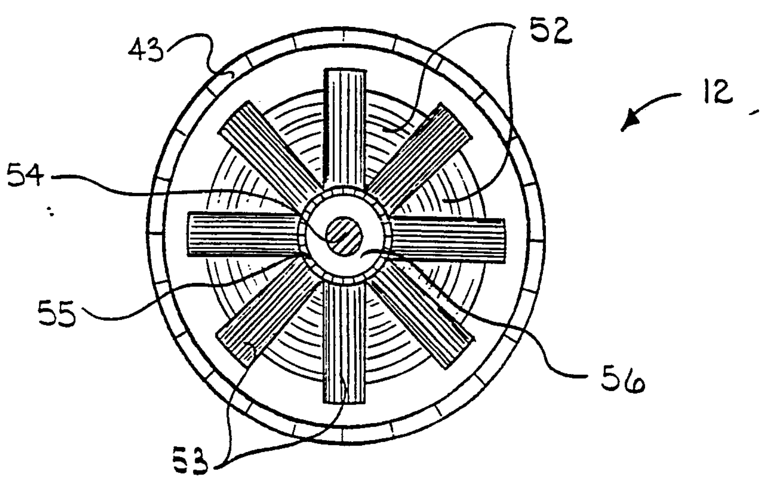

FIGURE 10

INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/03265

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5): H02K 44/06

U.S.Cl.: 417/50

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	417/50 164/500,513

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
A	US, A, 4,398,589 (ELDRED) 16 August 1983 (Em Pump has idle mode - see abstract)	1-4
Y	US, A, 4,714,102 (KOYA) 22 December 1987 (Col. 2, lines 50-57 & col. 4, lines 56-64)	1, 2, 3
Y	US, A, 4,733,714 (SMITH) 29 March 1988	1, 2, 3
Y	US, A, 4, 828,459 (BEHRENS) 09 May 1989 (see col. 5, lines 29 & 33)	4
X P	US, A, 4,928,933 (MOTOMURA) 29 May 1990 (Two groups of coils, see abstract)	1

* Special categories of cited documents: [15]

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
03 July 1990	08 NOV 1990
International Searching Authority [1]	**Signature of Authorized Officer** [20]
ISA/US	David W. Scheuermann

Form PCT/ISA/210 (second sheet) (May 1986)